

Article

Petrophysical Evaluation of Lower Jurassic Carbonates in Northeast Iraq: Insights from Shale Volume and Porosity Analysis

Mohammed Y. Najmuldeen¹, Khairallah Mohammed Abdullah Al-Obaidy²

1. Petroleum Engineering Department, College of Engineering, University of Kirkuk, Kirkuk, Iraq

2. Petroleum Training Institute - Refining Department – Iraq

* Correspondence: mhmdpet@uokirkuk.edu.iq

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Abstract: The current paper examines the petrophysical characteristics and reservoir potential of the Lower Jurassic Alan, Mus, and Adaiyah formations in two wells in the Kurdistan Region, northeast of Iraq. The conventional wireline logs (gamma ray, density, neutron, and sonic) were processed with the Techlog software to determine shale volume and porosity. Findings indicate that there is a high stratigraphic control over shale and porosity distribution. The most argillaceous unit is the Alan Formation, whose shale content is over 15 percent, and the porosity is negligible (less than 0.5 %), which means that the reservoir quality is poor. Mus Formation has the least shale content (2-6%) and the highest effective porosity (up to 6%), which makes it the target interval. The Adaiyah Formation exhibits intermediate characteristics, and the top layers (AD1 to AD3) are characterized by enhanced porosity (3 to 6%) and decreased shale content. The observations of the inverse relationship between effective porosity and shale volume in both wells can be discussed in terms of regional and international investigations of the Jurassic carbonate reservoirs in the Arabian and Tethyan basins. These results establish a positive correlation between the quality of the reservoir of the Lower Jurassic carbonates and the content of the shale and overprinting by diagenesis. The work offers a new perspective on the heterogeneity and reservoir performance of the Lower Jurassic carbonates in northern Iraq and is part of the overall knowledge of the petroleum system of the Jurassic in the Zagros foreland basin.

Keywords: Fractured Reservoirs, Lower Jurassic Carbonate Reservoirs, Shale Volume Estimation, Zagros Foreland Basin.

1. Introduction

A heterogeneous rock with large quantities of clay minerals, e.g., illite, kaolinite, and montmorillonite, which affect the petrophysical characteristics of carbonate reservoirs. Shale always decreases porosity and permeability, and hence lowers the quality of a reservoir [1], [2]. Therefore, shale volume (V_{sh}) estimation is an important reservoir assessment procedure. Well logging tools represent one of the important parameters for evaluating reservoir rocks, such as gamma-ray (GR) logs, which can be used to identify shale, and the clay minerals usually tend to concentrate the radioactive isotopes of potassium (K), uranium (U), and thorium (Th) that are naturally occurring [3]. Moreover, the determination of porosity through well logs is based on the reaction of various physical properties of the subsurface formations to logging tools. Density, neutron, and sonic logs are standard methods that are sensitive to a variety of rock and fluid properties. The

density log reading is based on electron density to identify porosity, the neutron log determines hydrogen concentration, and the sonic log is based on acoustic transit time measurements, which are responsive to both matrix structure and pore structure. Taken together, these measurements can be better used to assess porosity and compensate for lithological differences, fluid effects, and borehole conditions [4], [5], [6]. This work focused on the Jurassic carbonate successions of northern and northeastern Iraq, which are significant petroleum intervals of the Zagros foreland basin (Fig. 1). The Alan, Mus, and Adaiyah formations are known to have been considered as potential hydrocarbon reservoirs due to stratigraphic thickness, lateral extension, and depositional environment of these intervals. Nevertheless, the presence of shale and its distribution have a significant impact on the quality of their reservoirs, lowering effective porosity and permeability, and therefore regulating the capacity to store and produce hydrocarbons. In this work, an integrated log dataset was utilized to accurately determine the volume of shale, determine the effective porosity, determine and evaluate the prospects of hydrocarbon-bearing units, and outline the areas of best promise for future detailed study.

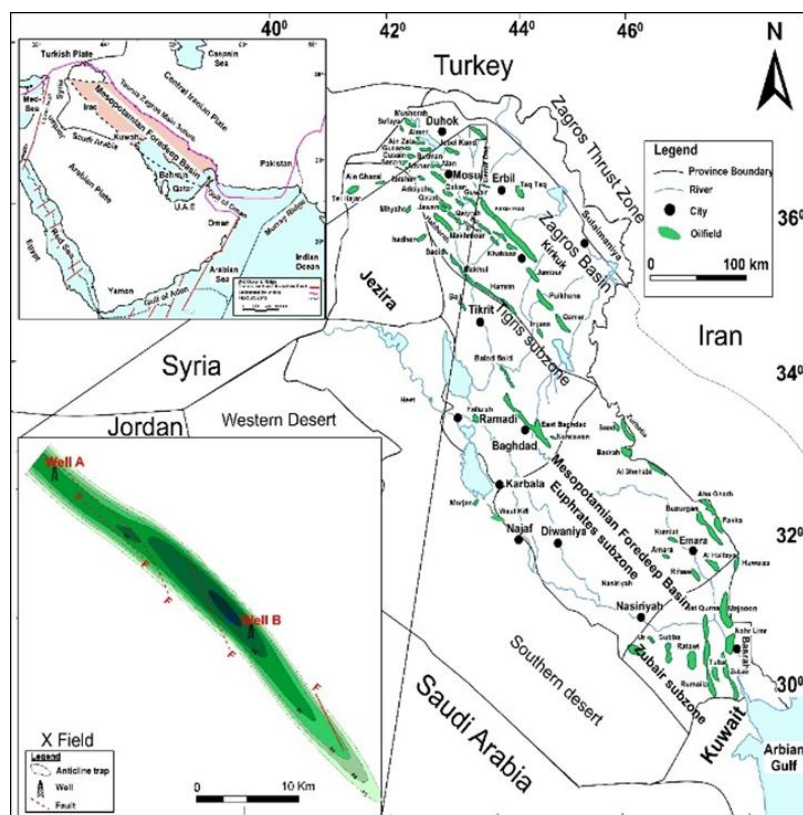


Figure 1. Tectonic map of Iraq showing the location of the examined field and the well location (Gharib et al., 2024).

2. Materials and Methods

In this work, a combined well logging data were obtained at two wells (Well A and Well B) in the X field, northeast Iraq. The dataset included gamma ray (GR), density (RHOB), neutron porosity (NPHI), and sonic (DT) logs. These logs covered the Lower Jurassic succession, including the Alan, Mus, and Adaiyah formations. Schlumberger Techlog 2015 software was used to process and interpret the data to analyze shale volume and effective porosity (Tables 1-2).

Table 1. Calculated volume of shale (Vsh) in the investigated formation for both well A and well B.

Well	Formation	Zone	Top (MD)	Bottom (MD)	Zne thickness (m)	Formation thickness	Zone Vsh	Formation Vsh
Well A	Alan	A1	1961	1981	20	95.8	0.15	0.15
		A2	1981	2001	20		0.2	
		A3	2001	2021	20		0.14	
		A4	2021	2041	20		0.1	
		A5	2041	2056.8	15.8		0.18	
	Mus	M1	2057	2076	19.2	100	0.03	0.056
		M2	2076	2096	20		0.02	
		M3	2096	2116	20		0.04	
		M4	2116	2136	20		0.04	
		M5	2136	2156.8	20.8		0.15	
	Adaiyah	AD1	2157	2176	19.2	126.2	0.1	0.17
		AD2	2176	2196	20		0.15	
		AD3	2196	2216	20		0.17	
		AD4	2216	2236	20		0.2	
		AD5	2236	2256	20		0.16	
		AD6	2256	2276	20		0.15	
		AD7	2276	2283	7		0.26	
Well B	Alan	A1	2041	2061	20	96.6	0.1	0.11
		A2	2061	2081	20		0.12	
		A3	2081	2101	20		0.11	
		A4	2101	2121	20		0.07	
		A5	2121	2137.6	16.6		0.14	
	Mus	M1	2138	2157	19.4	97.4	0.04	0.06

The gamma ray log is utilized in order to calculate the volume of shale in the reservoir rocks. In the first step, the gamma ray index IGR was calculated as shown in equation no. 1 (Asquith & Gibson, 1982).

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

Determined values of the IGR were used to calculate the volume of shale values based on Larinov's (Older rocks) calculation method, utilizing equation no. 2 (Asquith & Gibson, 1982).

$$V_{sh} = 0.33 \times (2^{2.1 \times IGR} - 1) \quad (2)$$

Porosity determination from NPHI, ROHB, and DT logs must be environmentally corrected with VSH as calibration and should be made based on the matrix densities and the formation lithology. The density porosity ($\emptyset_{dcor.}$) corrected utilizing equation 3 (Asquith & Gibson, 1982).

$$\emptyset_{dcor.} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (3)$$

Porosity determination from sonic log can be acquired using the Wyllie equation (Donaldson, 1989; Doveton, 1999), as presented in equation no. 4, where Δt_f for fresh water is equal to 189 $\mu\text{sec/ft}$, and salt water mud=185 $\mu\text{sec/ft}$.

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}} \quad (4)$$

Furthermore, the effective porosity $\emptyset E$ (PHIE) can be calculated using equation no. 4 (Asquith & Gibson, 1982).

$$\emptyset E (PHIE) = \emptyset T (PHIT) \times (1 - V_{sh}) \quad (5)$$

Table 2. Effective porosity values in the investigated formation for both well A and well B.

Well	Formation	Zone	Top (MD)	Bottom (MD)	Thickness (M)	Ø N-D (PHIE)	Ø N-S (PHIE)	ØE true (PHIE)
Well A	Alan	A1	1961	1981	20	0.01	0.004	0.004
		A2	1981	2001	20	0.01	0	0
		A3	2001	2021	20	0.002	0.001	0.001
		A4	2021	2041	20	0	0	0
		A5	2041	2056.8	15.8	0.003	0	0
	Mus	M1	2057	2076	19.2	0.08	0.06	0.06
		M2	2076	2096	20	0.06	0.05	0.05
		M3	2096	2116	20	0.06	0.04	0.04
		M4	2116	2136	20	0.06	0.04	0.04
		M5	2136	2156.8	20.8	0.03	0.01	0.01
	Adaiyah	AD1	2157	2176	19.2	0.05	0.024	0.02
		AD2	2176	2196	20	0.02	0.007	0.005
		AD3	2196	2216	20	0.01	0.005	0.004
		AD4	2216	2236	20	0.01	0.004	0.003
		AD5	2236	2256	20	0	0.002	0.001
		AD6	2256	2276	20	0.02	0.013	0.013
		AD7	2276	2283	7	0.01	0.004	0.003
Well B	Alan	A1	2041	2061	20	0.003	0.003	0.002
		A2	2061	2081	20	0	0.001	0
		A3	2081	2101	20	0	0	0
		A4	2101	2121	20	0	0	0
		A5	2121	2137.6	16.6	0	0	0
	Mus	M1	2138	2157	19.4	0.04	0.05	0.04
		M2	2157	2177	20	0.03	0.04	0.03
		M3	2177	2197	20	0.03	0.05	0.02
		M4	2197	2217	20	0.01	0.02	0.01
		M5	2217	2235	18	0.007	0.01	0.007
	Adaiyah	AD1	2235	2255	20	0.05	0.11	0.03
		AD2	2255	2275	20	0.006	0.11	0.007
		AD3	2275	2291	16	0.006	0.13	0.06

3. Results and Discussion

Volume of shale Distribution. The gamma ray-derived shale volume (Vsh) has been corrected using the Larionov (1969) older-rock equation, exhibiting specific variability both across formations and within wells (Table 1; Fig. 2). In Well A, the Alan Formation is 15% shale on average, with some areas going up to 20-30%. In Well B, the shale volumes are low, with an average Vsh reaching up to 11%. Both wells consistently exhibit the cleanest interval in their Mus Formation, with shale volumes ranging from 2 to 6%. In comparison, the Adaiyah Formation is more heterogeneous, 17% in Well A and 10% in Well B, with peak values of more than 25% in the Adaiyah Formation bottom (AD7 in Well A). These findings reveal that the Mus Formation has minimal shale content, and the Alan and Adaiyah formations have increased argillaceous input, reducing the quality of the reservoirs. These results are comparable to analogous structures in the Zagros Basin and in the Jurassic carbonate-shale sections of the Arabian Plate [7], [8], [9], [10], in which marine restriction and terrigenous importation play a significant role in controlling the quality of the reservoir.

Effective Porosity. The neutron-density and neutron-sonic porosities are corrected to obtain effective porosity (ϕE), which exhibits similar stratigraphic patterns (Table 2; Fig.

3). In Well A, the Alan Formation has an insignificant porosity (less than 0.5%), indicating its poor reservoir properties.

The Mus Formation has the highest effective porosities (PHIE), with a peak of 6% in the upper zones of the formation (M1–M3), and a decrease to 1–2% in the lower parts (M5). Well A has a heterogeneous Adaiyah Formation with PHIE ranging from 0.2% to 2% and exhibits the greatest development in the uppermost zones (AD1). The Alan Formation again contributes virtually no useful porosity in Well B. The Mus Formation has a moderate average PHIE of 24% in its upper part, and declining to the bottom. In Well B, the Adaiyah Formation is more promising than in Well A, consistent with a PHIE between 3%–6% (AD3). These differences reveal the heterogeneity of the locality in terms of carbonate reservoir development in the study area. Similar patterns have been reported in Jurassic carbonates in the Arabian and Persian basins [11], [12], [13], where intergranular and secondary porosity is selectively maintained in clean, micritic, or bioclastic facies with low shale content.

Volume of shale and porosity data integration. The powerful influence of shale content on the quality of the reservoir rocks, highlights the integration of shale volume and PHIE (Tables 1–2; Figs. 2–3). The clean carbonate units of the Mus Formation are associated with maximum effective porosities, with maximum values of 6% in Well A and 4% in Well B. Likewise, in the Adaiyah Formation, the increase of porosity is concentrated in the higher levels (AD1–AD3), where the volume of the shale reduces and the effective porosity is enhanced. Conversely, the Alan Formation is always high in shale and has insignificant porosity, making it non-reservoir [14], [15], [16].

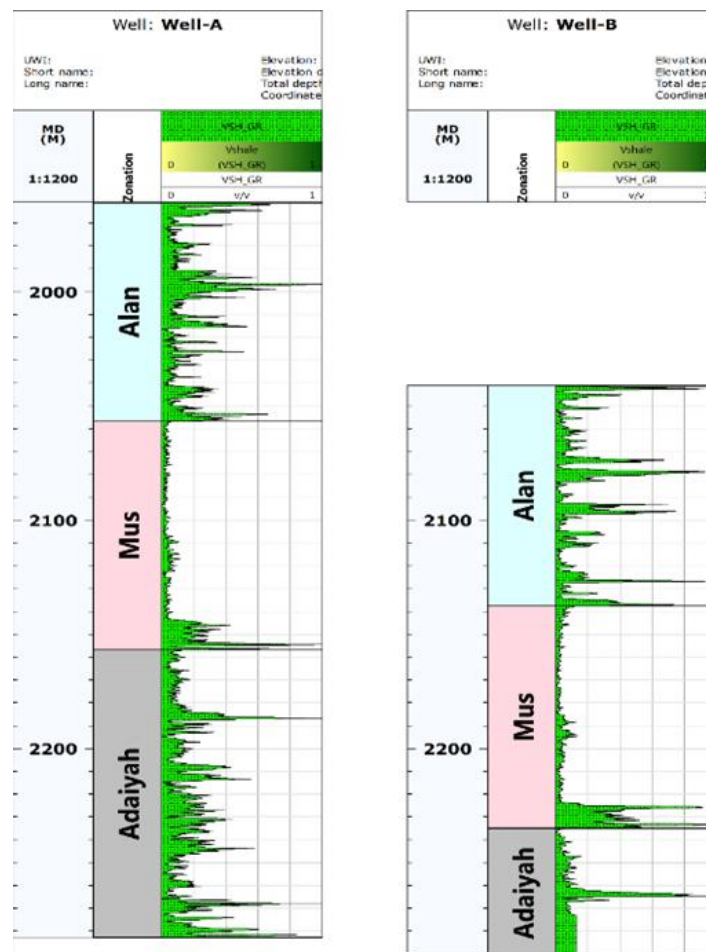


Figure 2. The calculated volume of shale of the Jurassic formation within wells A and B.

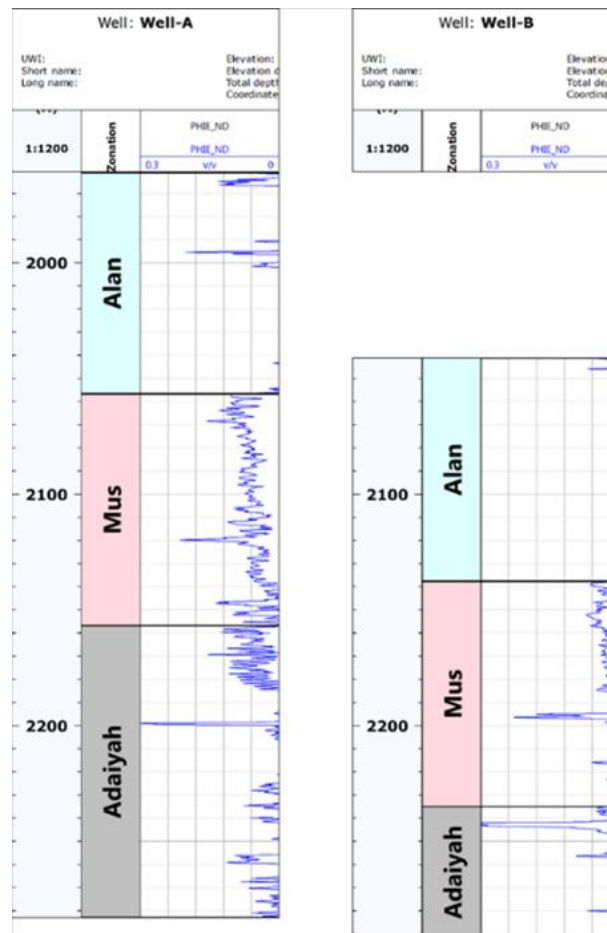


Figure 3. The calculated effective porosity (PHIE) of the Jurassic formation within wells A and B.

4. Conclusion

The Lower Jurassic in the Zagros Basin is composed of three major carbonate units, which are the Alan, Mus, and Adaiyah, and have varying shale and porosity properties. The highest values of the shale volume (Vsh) are recorded in the Alan Formation (10-20%), followed by the Adaiyah Formation (10-26%), and finally the lowest in the Mus Formation (2-6%). Trends of effective porosity (ϕ_E) are negatively proportional to shale content: the best reservoir quality is the Mus Formation (maximum ϕ_E 6%), whereas the Alan Formation has zero porosity. Adaiyah Formation is a good example of vertical heterogeneity, as the upper zones (AD1–AD3) exhibit moderate porosity and can be used as secondary reservoirs. The strong relationship between low shale content and high porosity is consistent with regional and international data of the Jurassic carbonate reservoirs of the Arabian and Tethyan basins, which implicates shale fraction as the primary determinant of pore connectivity. The Mus Formation is ranked as the most promising reservoir target, and the Alan Formation could be used as a useful intraformational seal. These findings emphasize the dual effects of depositional and diagenetic processes on reservoir heterogeneity and the importance of combined petrophysical and geological analysis in future exploration of the Zagros foreland basin.

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REFERENCES

- [1] D. Alkaki, D. Al-Bayati, M. Al-Mufarji, and S. Mohammed, "Assessment of shale volume estimation using non-linear approaches for Jeribe Formation in Jambour Oil Field, Northern Iraq," *The Iraqi Geological Journal*, pp. 187–197, 2025, doi: 10.46717/igj.2025.58.1E.14.
- [2] A. S. Alsharhan and K. Magara, "Nature and distribution of porosity and permeability in Jurassic carbonate reservoirs of the Arabian Gulf Basin," *Facies*, vol. 32, no. 1, pp. 237–253, 1995, doi: 10.1007/BF02536872.
- [3] G. B. Asquith and C. R. Gibson, *Basic Well Log Analysis for Geologists*, vol. 3. Tulsa, OK, USA: American Association of Petroleum Geologists, 1982.
- [4] A. Assadi, H. Rahimpour-Bonab, and R. Kadkhodaie-Ilkhchi, "Integrated rock typing of the grainstone facies in a sequence framework: A case from the Jurassic Arab Formation in the Persian Gulf," *Acta Geologica Sinica (English Edition)*, vol. 92, no. 4, pp. 1432–1450, 2018, doi: 10.1111/1755-6724.13636.
- [5] R. Baouche, K. Boutaleb, and R. Chaouchi, "Effect of petrophysical and sedimentological properties on the heterogeneity of carbonate reservoirs: Impact on production parameters," in *Sustainable Civil Infrastructures*. Cham, Switzerland: Springer, 2020, pp. 118–124, doi: 10.1007/978-3-030-34178-7_10.
- [6] Y. Ding, "The application of natural gamma spectrometry log to limestone reservoir in T oilfield of Middle East," *Geophysical and Geochemical Exploration*, 2014.
- [7] E. C. Donaldson, "Well logging for earth scientists," *Journal of Petroleum Science and Engineering*, vol. 2, no. 4, p. 389, 1989, doi: 10.1016/0920-4105(89)90013-2.
- [8] J. H. Doveton, *Basics for Oil & Gas Log Analysis*. Lawrence, KS, USA: Kansas Geological Survey, 1999.
- [9] Dresser Atlas, *Log Interpretation Charts*. Houston, TX, USA: Dresser Industries, 1979.
- [10] M. S. El-Yamani, K. Al-Ramadan, and D. L. Cantrell, "Diagenetic controls on porosity evolution and reservoir quality of an outcrop analogue of the Jurassic carbonate reservoirs in the Arabian Plate: An example from the Middle Jurassic Tuwaiq Mountain Formation, Central Saudi Arabia," *Journal of Petroleum Science and Engineering*, vol. 208, Art. no. 109669, 2022, doi: 10.1016/j.petrol.2021.109669.
- [11] A. F. Gharib, A. S. Abbas, and S. E. Mohammed, "Organic geochemical investigation and 1D basin modeling of the Chia Gara source rock (Tithonian–Berriasian) interval in the Zagros Basin, Iraq: Implications for oil generation potential," *Carbonates and Evaporites*, vol. 39, no. 4, Art. no. 108, 2024, doi: 10.1007/s13146-024-01029-1.
- [12] A. F. Gharib and A. M. Özkan, "Reservoir evaluation of the Tertiary succession in selected wells at Ajeel Oilfield, Northern Mesopotamian Basin, NE Iraq," *Arabian Journal of Geosciences*, vol. 15, no. 12, pp. 1–18, 2022, doi: 10.1007/s12517-022-10419-5.
- [13] M. M. Mahdi, M. J. Ismail, and O. A. M. Mohammad, "The integration of wireline logs and sedimentological data to predict sequence stratigraphic framework in carbonate rocks: An example from Rumaila Formation (Cenomanian), West Qurna Oil Field, Southern Iraq," *Stratigraphy and Geological Correlation*, vol. 30, no. 5, pp. 360–377, 2022, doi: 10.1134/S0869593822050045.
- [14] W. J. Mamaseni, S. F. Naqshabandi, and F. K. Al-Jaboury, "Petrophysical properties of the Early Cretaceous formations in the Shaikhan Oilfield, Northern Iraq," *Earth Sciences Research Journal*, vol. 22, no. 1, pp. 45–52, 2018, doi: 10.15446/esrj.v22n1.66088.
- [15] G. Sherwani and H. Zangana, "Reservoir characterization of Early Jurassic formations in selected wells in the Duhok Governorate, Iraqi Kurdistan Region," *UKH Journal of Science and Engineering*, vol. 1, no. 1, pp. 11–18, 2017, doi: 10.25079/ukhjse.v1n1y2017.pp11-18.
- [16] T. Wu and R. R. Berg, "Relationship of reservoir properties for shaly sandstones based on effective porosity," *Petrophysics*, vol. 44, no. 5, pp. 331–340, 2003. (See also erratum in *Petrophysics*, vol. 44, no. 6, p. 379, 2003.)